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A REVIEW AND EVALUATION OF UNDERSEA SUBSIDENCE CRITERIA USED IN THE SYDNEY COALFIELD, N.S.

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by

T.R.C. Aston*

SUMMARY

In 1983, the Cape Breton Coal Research Laboratory initiated a long-term research program to review and evaluate undersea mining guidelines for the Sydney Coalfield, N.S. A major project within this program is the formulation of specific undersea subsidence guidelines, particularly regarding the maximum tensile strain that can be induced at seabed.

This report provides a background document which traces the origin and development of the U.S.A., U.K. and Sydney Coalfield seafloor tensile strain guidelines. Finally, relevant undersea mining research undertaken in the U.K. is reviewed and the applicability of the existing Sydney Coalfield guidelines discussed.

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EXAMEN ET ÉVALUATION DES CRITÈRES RELATIFS À LA SUBSIDENCE SOUS-MARINE UTILISÉS À LA HOUILLÈRE DE SYDNEY, (N.-E.)

par

T.R.C. Aston*

RÉSUMÉ

En 1983, le Laboratoire de recherche sur le charbon, au Cap-Breton, a entrepris un programme de recherche à long terme visant à réviser et évaluer les lignes directrices relatives à l'exploitation minière souterraine appliquées à la houillère de Sydney (N.-É.). Un des projets principaux élaboré dans le cadre du programme est la formulation de lignes directrices spécifiques portant sur la subsidence sous-marine, en particulier en ce qui concerne la déformation maximale due à la traction qui peut se produire dans le fond marin.

Le présent rapport se veut un document de référence retraçant les origines et le développement des lignes directrices relatives à la résilience du fond marin, élaborées au É.-U., en G.-B. et à la houillère de Sydney. Enfin, les activités de recherche souterraines entreprises en G.-B. sont passées en revue, et l'applicabilité des lignes directrices actuelles élaborées à la houillère de Sydney est étudiée.

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CONTENTS

	Page
SUMMARY	i
SOMMAIRE	ii
INTRODUCTION	1
CONSTRAINTS ON UNDERSEA MINING IN THE SYDNEY COALFIELD	1
Depth of Cover	1
1) Coal Mines (CBDC Safety Regulations)	1
2) Nova Scotia Provincial Coal Mine Regulations	2
Seabed Strains	2
DEVELOPMENT OF UNDERSEA SUBSIDENCE GUIDELINES	2
United Kingdom	2
Sydney Coalfield, Nova Scotia	3
United States of America	5
UNDERSEA MINING RESEARCH SINCE 1981	5
Minewater Occurrences and Seafloor Subsidence Criteria	6
University of Newcastle upon Tyne, U.K.	6
University of Nottingham, U.K.	10
In Situ Strata Permeability Changes associated with Longwall Mining	12
DISCUSSION	14
CONCLUSIONS	19
REFERENCES	20

TABLES

No.		Page
1.	Significance of relations - Northumberland Coalfield	8
2.	Significance of relations - Durham Coalfield	8

FIGURES

No.		Page
1.	Minimum distance of all wet panels from fault zones against quantity of water experienced	13
2.	Schematic diagram showing normal subsidence profile and the effects of a centre gate	15
3.	Relationship between maximum subsidence and the subsidence experienced over a centre gate	15

INTRODUCTION

In 1983, the Cape Breton Coal Research Laboratory (CBCRL) initiated a long-term research program to review and evaluate undersea mining guidelines for the Sydney Coalfield, Nova Scotia (1). A major project within this program is the formulation of specific seafloor subsidence guidelines. The need for this project stems from the difference in current U.S.A., U.K. and Sydney Coalfield theoretical maximum tensile strain values that can be induced at seabed (or the base of a major aquifer) before the risk of water ingress to the mine workings becomes unacceptable.

This report provides a background document which traces the origin and development of the U.S.A., U.K. and Sydney Coalfield seafloor tensile strain guidelines. In addition, relevant undersea mining research undertaken in the U.K. is reviewed along with a discussion of the applicability of the existing Sydney Coalfield guidelines.

CONSTRAINTS ON UNDERSEA MINING IN THE SYDNEY COALFIELD

Two principal constraints exist concerning the mining of undersea mineral reserves: Depth of Cover and Seabed Strains.

DEPTH OF COVER

Legally, undersea mining cannot be undertaken unless sufficient impermeable strata exists between the mining horizon and seabed to prevent the unacceptable ingress of water. Restrictions regarding the amount of cover vary according to the type of mining, percentage extraction and extracted seam height. In the Sydney Coalfield, the amount of cover is determined by the Canadian Labour Code - Coal Mines (CBDC) Safety Regulations (2), although a separate set of provincial regulations (3) also exist for Nova Scotia.

1) Coal Mines (CBDC) Safety Regulations

115 - No mine shall be worked below the sea bottom or below any other body of water except under the following conditions:

(a) No submarine seam of coal or stratified deposit shall be worked under less cover than 180 ft (54.9 m) of solid measure, except that

an owner or lessee of any area may drive passageways to win the mineral to be worked and such passageways may have a cover less than 180 ft (54.9 m) but not less than 100 ft (30.5 m) of solid measure (2).

2) Nova Scotia Provincial Coal Mines Regulations

In the working of coal or stratified deposits in submarine areas, the following provisions shall apply:

(a) No submarine seam of coal or stratified deposits shall be worked under less cover than one hundred and eighty feet of solid measures; provided that the owner or lessee of any area may drive passageways to win the mineral to be worked under less cover than one hundred and eighty feet (54.9 m) but not less than one hundred feet (30.5 m) of solid measures (3).

SEABED STRAINS

The current maximum tensile strain at seabed allowable in the Sydney Coalfield is 8.5 mm/m. This value was recommended in a report submitted by K. Wardell and Partners (4) to the 1974 Commission of Inquiry into undersea mining in Cape Breton.

The 1974 Wardell report (4) indicated that seafloor strains in the order of 8.5 mm/m have been produced by previous undersea workings in the Sydney Coalfield. They further stated that based on their equations and constants, no mining should take place that would result in seabed strains in excess of 8.5 mm/m. This conclusion was based primarily on the assumption that since no inundations had occurred in the past, then in the absence of any other relevant information, it would be unwise to further reduce the inherent factor of safety.

DEVELOPMENT OF UNDERSEA SUBSIDENCE GUIDELINES

UNITED KINGDOM

In 1968, the National Coal Board, U.K. issued a Production Department Instruction (PI/1968/8) 'Working Under the Sea' (5). In summary, this states that for extraction by longwall methods 'the cover between the worked

seam and seabed shall not be less than 105 m of which 60 m must be of carboniferous strata. The tensile strain at seabed shall not exceed 10 mm/m for both first and successive seam workings'. Similar criteria are also laid down in the instruction for extraction by 'room and pillar' methods.

The 10 mm/m limit for maximum tensile strain at seabed was derived arbitrarily, being arrived at on the basis of judgement and experience gained from many years of undersea longwall operations in a wide range of geological and mining conditions off the coast of Great Britain.

SYDNEY COALFIELD, NOVA SCOTIA

In 1974, K. Wardell and Partners submitted a report to the Commission of Inquiry on the question of submarine mining in Cape Breton (4).

The Wardell report (4) states that a universally acceptable equation for deriving the maximum tensile strain of a subsidence profile is:

$$E_m = \frac{k\ S_m}{D} \qquad \text{Eq 1}$$

which can be written:

$$E_m = \frac{k\ t\ a}{D} \qquad \text{Eq 2}$$

where E_m = Maximum tensile strain

S_m = Maximum subsidence

k = Mining/geological coefficient varying between 0.5 and 1.0

t = Extracted seam height

a = Waste caving coefficient

D = Depth of working

The coefficient 'a' is normally 0.9 for caving using modern longwall techniques and 0.8 for the historical mining method involving the installation of wall packs/wood chocks in the waste area (4).

An examination of historical records for the Sydney Coalfield revealed (4):

At the Dominion No. 17 mine, a wide area (approximately 2500 ft) of longwall mining in the Harbour Seam undertaken in the early 1960's at a depth

of cover between 700 ft and 1000 ft. The extracted seam height was 5.34 ft using the longwall method with wall packs. Assuming a critical area of extraction giving rise to the development of maximum subsidence and using equation 2 where k = 1.0 and a = 0.8:

$$E_m = \frac{1.0 \times 5.34 \times 0.8}{700} = 0.0061 \text{ or } 6.1 \text{ mm/m}$$

Further examination revealed an area of longwall working in the No. 20 mine (Harbour Seam 1961/65 - depth of cover 920 ft - extracted seam height 5.0 ft) overlaying a pillar drawn area of the No. 2 mine (Phalen Seam 1936/37 - depth of cover 1380 ft - extracted seam height 7.0 ft). Assuming a critical area where the maximum tensile strains are superimposed and cumulative, then using equation 2 where k = 1.0 and a = 0.8:

At No. 20 mine, $$E_m = \frac{1.0 \times 5.0 \times 0.8}{920} = 4.34 \text{ mm/m}$$

At No. 2 mine, $$E_m = \frac{1.0 \times 7.0 \times 0.8}{1380} = 4.05 \text{ mm/m}$$

Cumulative tensile strain = 8.39 mm/m

At Lingan mine, the 1E panel (Harbour Seam - depth of cover 800 ft - extracted seam height 6.0 ft) is the first submarine longwall caving panel to be worked. Assuming a critical area and using equation 2 where k = 1.0 and a = 0.9:

$$E_m = \frac{1.0 \times 6.0 \times 0.9}{800} = 6.75 \text{ mm/m}$$

It is also mentioned that since tensile strain is derived empirically, the coefficients used were derived from many detailed subsidence observations in the U.K. and Europe. Great care must therefore be taken when transposing these values, especially since no detailed observations of surface subsidence are available for the derivation of Sydney Coalfield specific coefficients.

UNITED STATES OF AMERICA

In 1976, K. Wardell and Partners undertook a detailed study for the U.S. Bureau of Mines (6) to formulate practical guidelines for active mining in close proximity to water bodies. This was accomplished through the systematic completion of three study phases:

1) Collection and documentation of data,
2) Application of existing guidelines to previous inundation case histories, and
3) Development of recommended guidelines for underground coal mining near bodies of water.

This report (6) recommends that any single coal seam worked close to or under a surface body of water by either longwall mining or pillar drawing, should leave a minimum of 60 ft of solid strata cover between the proposed workings and the surface water body for each 1.0 ft of coal seam extracted.

In addition, subsidence observations from the Appalachian Coalfield of the U.S.A. and the New South Wales Coalfield of Australia suggest that maximum subsidence is between 0.6t and 0.7t (a = 0.6 to 0.7) compared with the values of 0.8t and 0.9t (a = 0.8 to 0.9) observed in Europe.

Using equation 2, where k = 0.75 and a = 0.7:

$$E_m = \frac{0.75 \times 0.7 \times t}{60t} = 8.75 \text{ mm/m}$$

The 1976 Wardell report states that the average value of k for the U.K. is 0.75. The value of k = 0.75 derived from U.K. data is therefore assumed to be representative of North American conditions.

In the report (6), it recommends that 'any number of seams maybe mined by total extraction provided the maximum cumulative, calculated tensile strain beneath the surface water body will nowhere exceed 8.75 mm/m.

UNDERSEA MINING RESEARCH SINCE 1981

Research undertaken into undersea coal mining since 1981 and applicable to the Donkin-Morien project can be divided into two main areas:

1) Minewater occurrences and seafloor subsidence criteria.

2) In situ strata permeability changes associated with longwall mining.

MINEWATER OCCURRENCES AND SEAFLOOR SUBSIDENCE CRITERIA

University of Newcastle upon Tyne, U.K.

In 1980, a Ph.D. thesis was submitted to the University of Newcastle upon Tyne which examined the effects of mining on surface and subsurface water bodies (7). This work was undertaken in the North-East of England Coalfield and involved a detailed statistical examination of water inflow data against a variety of mining and geological parameters for the Northumberland and Durham Coalfields.

At the onset of the work it was assumed to be highly improbable that the water occurrences experienced in the North-East Coalfield could be expressed as a function of one or more factors related to the basic controlling conditions (8):

(a) Cover to the Permian or seabed.

(b) The maximum tensile strain induced at the base of the Permian or seabed calculated from the SEH (9).

(c) The aggregate tensile strain induced at the base of the Permian or seabed including estimates of strains from adjacent workings in the same seam.

(d) The total tensile strain at the base of the Permian or seabed including estimates of strain from all workings in the same and adjacent seams.

(e) The ratio between the head of water at the base of the Permian and the carboniferous cover.

(f) Strata inhomogeneities and geological structure.

(g) Strata lithology, in particular the percentage of sandstones in the succession beneath the Permian or seabed.

The data obtained was therefore analysed using non-parametric or 'distribution free' tests which require no assumptions concerning the distribution of the observed data. The 'rank sum' test was adopted to test the hypothesis that the medians of two populations are equal against a specified alternative. The populations must be assumed to be continuous and have the same form (7, 10).

The data was analysed to test the hypothesis that the median of the wet and dry face populations are equal. For the purpose of analysis, wet faces were considered in two basic groupings, those which encountered water in quantities in excess of 4 l/sec and those which liberated feeders greater than 20 l/sec. Results indicating a correlation at the 5% level were treated as being 'significant', while a correlation at the 1% level was considered 'highly significant' (8). The statistical data is summarized in Tables 1 and 2.

In Northumberland (8), the incidence of feeders in excess of 20 l/s appears to be principally a function of the lithology of the overburden, although the cover to the seabed would also seem to be of some significance. Parameters related to the magnitude of the disruption induced in the strata between seam and seabed have comparatively little correlation with the incidence of major feeders.

In this light, the regulation currently controlling offshore extraction appears to guard adequately against inundation of workings directly by the sea, although it should be noted that no individual operations have induced the full 10 mm/m seabed strain allowed by the undersea working instruction (8). Operations appear to be at special risk of encountering feeders in excess of 20 l/s where:

a) Cover to the seabed is less than 140 m. This probably reflects the comparative ease with which overlying coal measure aquifers are replenished by the sea, and the increased porosity and permeability of aquifers subjected to erosional stress relief.

b) Major coal measure aquifers exist within 45 m or so of workings.

c) The competence of the immediate seam roof is comparatively low; that is where the first 20 to 30 m of overlying strata contains less than about 35% sandstone.

d) Work is prosecuted in the vicinity of faults, particularly those which hade towards workings.

Incidence of feeders of 4 l/s or more seems to be a function of the presence of sandstone aquifers in proximity to the workings. Notable influxes of water are associated principally with aquifers within 45 m or so of the seam being worked, which for many Yard, Main, High Main and Ashington seam operations implies the major aquiferous sandstone sequence above the horizon of the Ashington seam. This does not imply, however, that longwall

Table 1 - Significance of relations - Northumberland Coalfield

FEEDERS >20 l/s		FEEDERS >4 l/s	
"Z" Factor	Parameter	"Z" Factor	Parameter
4.72	Sandstone >20 m	9.12	Sandstone >20 m
2.67	Sandstone >30 m	6.80	Sandstone <45 m
-2.66	Cover	6.13	Sandstone <20 m
1.80	Sandstone >45 m	5.68*	W/H Ratio
-1.24	Sandstone <30 m	4.79	Sandstone <30 m
1.00	Head/Cover Ratio	-3.10*	Individual Strain
-0.79	Sandstone <20 m	-2.94*	Aggregate Strain
0.47	Sandstone <45 m	2.46*	Head/Cover Ratio
0.38	Individual Strain	2.46	Sandstone >30 m
0.20	W/H Ratio	0.88*	Cover
-0.19*	Aggregate Strain	-0.41	Sandstone >45 m

*Indicates that the parameter is related to incidence of water feeders in the opposite sense to what would logically be expected. "Z" values of 2.32 or more indicate a "highly significant" correlation and values greater than 1.64 a "significant" correlation.

Table 2 - Significance of relations - Durham Coalfield

FEEDERS >20 l/s		FEEDERS >4 l/s	
"Z" Factor	Parameter	"Z" Factor	Parameter
-5.17	Cover	6.85	Individual Strain
5.12	Individual Strain	6.78	W/H Ratio
4.54	Aggregate Strain	-6.29	Cover
4.17	Head/Cover Ratio	6.20	Head/Cover Ratio
3.49	W/H Ratio	5.44	Aggregate Strain
-2.18	Sandstone <45 m	-2.40	Sandstone <20 m
-1.37	Sandstone <30 m	-1.37	Sandstone >30 m
-1.16	Sandstone <20 m	-1.28	Sandstone <45 m
0.78	Sandstone >45 m	-0.75	Sandstone >20 m
-0.53	Sandstone >20 m	-0.26	Sandstone <30 m
-0.44	Sandstone >30 m	-0.27	Sandstone >45 m

"Z" values of 2.32 or more indicate a "highly significant" correlation and values greater than 1.64 a significant correlation.

operations cannot tap the water of aquifers at greater height. It is interesting that feeders have been encountered at depths below the seabed of up to 200 m, which indicates that sandstones are water bearing at depth. Total extraction systems will generally liberate feeders from nearby coal measure aquifers, a circumstance which should be borne in mind during layout planning and design. However, feeders encountered at depth and in the absence of faults and dykes will usually amount to no more than a nuisance.

In the Durham Coalfield (8), parameters related to the magnitude of deformations induced in the strata between workings and the Permian have the most significant correlation with the incidence of water feeders. Lithological considerations appear of secondary importance, although there is a general correlation between lower proportions of overburden sandstone, especially in the immediate seam roof and the incidence of water feeders.

Consideration of the above and individual case histories suggests that the incidence of noteable water feeders is essentially a function of dynamic strata fracturing occurring at the time of major roof breaks. This, induces open, effectively continuous, discontinuities within the overburden, which are capable of transmitting water into workings from overlying aquiferous formations, notably the Permian and sandstones in proximity to it. It is possible that a calculated tensile strain of 6 or 7 mm/m induced at the base of the Permian reflects a "critical" degree of fracturing for "average" conditions.

Workings in Durham appear to run a comparatively high risk of inundation where:

a) The cover to the Permian is less than 100 m,
b) Individual tensile strains calculated at the base of Permian exceed 6 mm/m,
c) The total net tensile strain induced at the base of Permian is greater than 12 mm/m, taking into consideration (b) above,
d) The overburden comprises less than 35% of sandstone, and
e) Adequate roof control is not maintained and major strata breaks are allowed to form.

In addition (8), the incidence of water has often been associated with strata discontinuities.

Considering the igneous dyke formations and their association in the North-East with water filled cavities or heavily watered zones, it is not

surprising that feeders have been encountered during development operations and while working faces alongside them.

Water in quantity has not generally been associated with faults, especially depostional faults, having throws ranging up to 1 m. However, when water is encountered, the yield tends to be greatest in the vicinity of the fault. Increased risk is apparent where workings approach or encounter:

a) Faulting approximately parallel to the faceline, which aggravates strata control difficulties,
b) Faults which hade over workings,
c) Faults of increasing throw,
d) Faults whose location suggests a significance beyond that indicated by consideration of throw alone: e.g. faults against which smaller faults terminate, and
e) Large faults where strata disruption and dislocation are greatest.

Feeders in Durham have also been encountered by operations in the vicinity of the folowing geological features:

a) Swalley banks,
b) Areas of steeply dipping strata or dip workings in faulted blocks,
c) Areas of rapidly increasing dip,
d) Monoclinal structures,
e) Lenticular sandstones,
f) The incrop to the Permian of major sandstone aquifers,
g) Massive aquiferous roof sandstones, and
h) Major roof jointing parallel to the faceline.

University of Nottingham, U.K.

In 1982, a Ph.D. thesis was submitted to the University of Nottingham which examined the hydrogeological aspects of mining subsidence and rock mechanics associated with longwall coal mining (11). This work formed part of an extensive research program to evaluate in situ permeability changes in coal measures strata associated with longwall coal mining.

Initially, a review of existing work (12) revealed that water occurrences experienced on longwall panels in the North-East of England Coalfield could not be readily attributed to the normally defined parameters of panel width, depth, width/depth ratio or tensile strain predicted at a major aquifer horizon (seabed or the base of Permian). A detailed evaluation of

water occurrences at four mines in the North-East Coalfield, namely Blackhall, Horden, Dawdon and Westoe, was therefore undertaken to examine the relationship between the water occurrences and either the tensile strain predicted at a major aquifer horizon (including those identified in the overlying coal measures strata) or the geological/hydrogeological conditions existing around the mine workings (11, 13).

A preliminary examination of the water yield - predicted tensile strain and geological - strain - water criteria at the Blackhall and Westoe mines revealed that water could be expected on any longwall face mined in close proximity to a large fault, where potential aquifer horizons have been thrown into close proximity with the working seam (14). It should be noted that the Blackhall, Horden and Westoe mines all experienced major water occurrences on longwall faces under a variety of mining and geological conditions. However, no major water occurrences have ever occurred in the Dawdon workings, even though extensive multiseam mining has taken place (13).

Tensile strain values predicted at the major aquifer horizons of each mine were calculated using the NCB SEH (9). It is recognised that this is an oversimplification which involves the use of the SEH for predicting subsidence and strain values at sub-surface as well as strata surface horizons.

At the three wet mines, exploratory and drainage boreholes failed to encounter water in quantity from any of the potential aquifer horizons in the overlying strata. However, subsequent panel extraction resulted in significant quantities of water being yielded. It therefore appears that the potential aquifer horizons only dissipate their stored water once the strata has been disrupted and that the primary mechanism of flow is via induced fracture permeability.

Examination of data from the four mines studied has revealed that water is encountered whenever, 'faces are worked in the vicinity of a major fault, where potential aquifer horizons (the Permian) have been displaced against coal measures strata overlying the working area'. At each of the wet mines, water was encountered in workings of the top most seam on faces worked in the vicinity of a fault with the aforementioned conditions. Faces in underlying seams worked in close proximity to the same type of fault have seldom encountered water in more than nuisance quantities.

Figure 1 shows minimum distances between the fault and working panel against the maximum and current/residual yields on wet faces at each of the three mines. In general, water is encountered on faces which have been worked closer than 350 m to the fault. No evidence exists to suggest that 'the closer the fault, the greater the amount of water liberated to the face'. It should also be noted that in every case, a well developed sandstone horizon was present in the strata sequence overlying the wet seam.

No evidence was found during the investigation that the magnitude of tensile strain induced at the base of Permian (BOP) affected the incidence of water on faces. At Horden and Westoe, multiseam workings induced predicted tensile strains of up to 12 mm/m and 14 mm/m respectively, at BOP without influencing the occurrence of water in workings of the top most seam. It is therefore concluded that away from major fault zones, the predicted tensile strain of 10 mm/m using the NCB SEH method can be exceeded without the increased likelihood of water.

In the vicinity of major faults, it is not apparent whether tensile strain or properties of the secondary aquifer systems control the amount of water yielded. However, at Blackhall and Horden, narrow faces and associated low tensile strains have resulted in water quantities as large as any of those experienced on wider faces. It is therefore concluded that properties of the secondary aquifers and intervening strata probably exert significant influence over the potential water yield.

IN SITU STRATA PERMEABILITY CHANGES ASSOCIATED WITH LONGWALL MINING

Extraction of coal by longwall mining results in a redistribution of stress in the surrounding strata. This in turn causes 'strata failure' on both the micro and macro level, with a resultant change in the in situ permeability. A change in strata permeability can affect the migration of fluids, such as water or methane, through the rock mass and into the mine workings. Gradual or rapid changes in these migrations can alter localised mining conditions and leak under exceptional circumstances to disasterous consequences.

During the 1970's, a research group in the U.K. conducted a series of investigations using field techniques to monitor in situ permeability changes within British coal measures strata (15,16,17,18). In the early 1980's, this was re-evaluated (19,20) and the conclusion revealed that changes in strata permeability can be linked to the ground strains induced

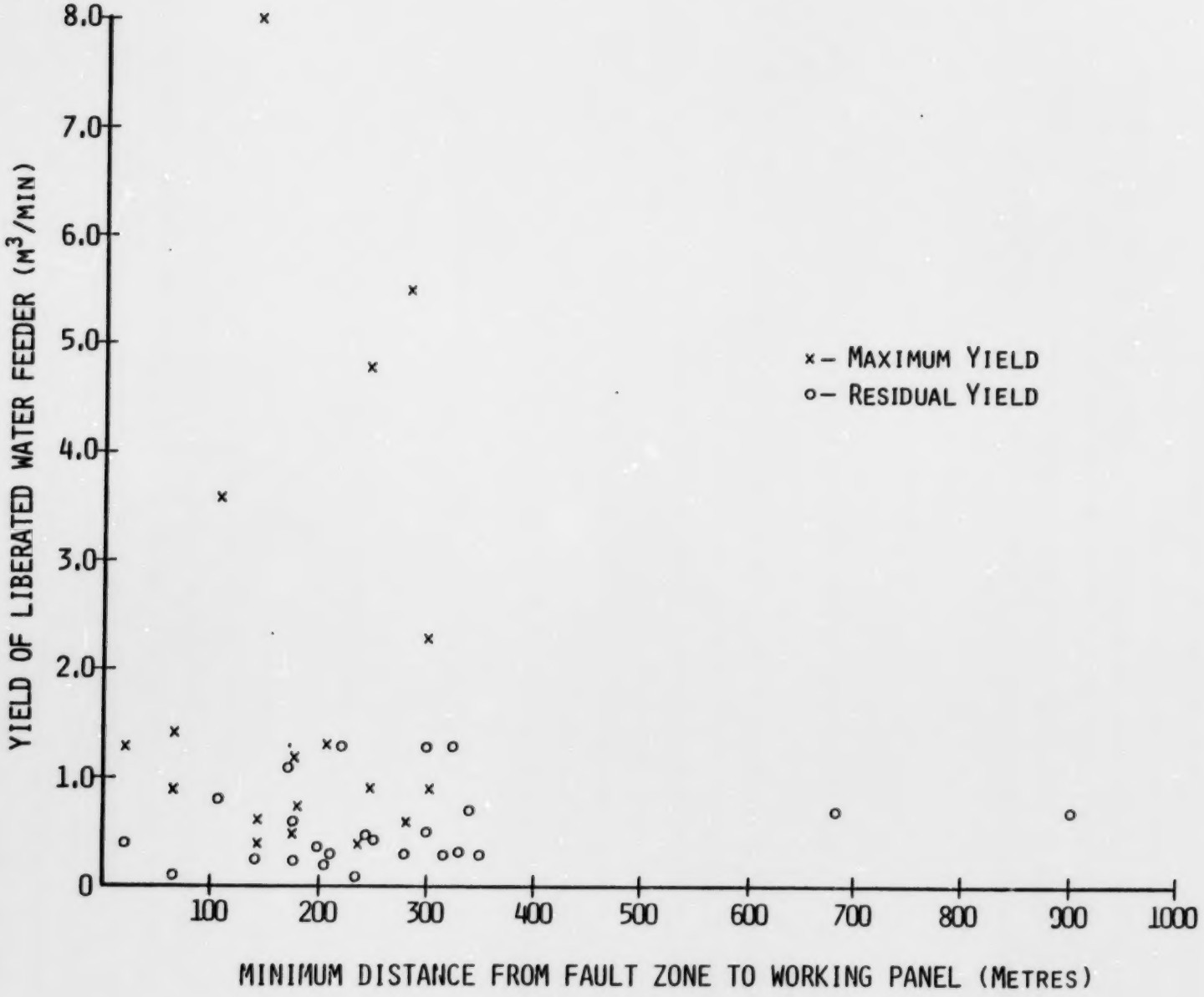

Figure 1 - Minimum distance of all wet panels from fault zones against quantity of water experienced (13)

around longwall extractions during subsidence profile formation. In addition, the magnitude of the induced permeability changes appear to be significantly affected by the geology of the overlying strata. However, insufficient data currently exists to quantify these effects and either confirm or dispute any of the proposed model concepts postulated by various research workers (19,21). Data from a great many sites is still required before permeability changes occurring around a longwall extraction can be either comprehensively understood or predicted using empirical methods.

DISCUSSION

In Wardell's 1974 report (4), values of a = 0.8 (in equation 2) were used to calculate the cumulative tensile strain induced at seabed over two overlying mined out areas in the No. 2 and No. 20 mines. In the No. 20 mine, Harbour Seam, the face width was 700 ft and since the centre gate packs were only 20 ft wide at a depth of 900 to 1000 ft, they are unlikely to have been sufficiently strong to prevent crushing. It is also thought that the pillar drawn areas in the No. 2 mine, Phalen Seam, would be totally caved. Both the No. 2 and No. 20 mine areas could therefore be treated as longwall wastes, resulting in a value of a = 0.9 being substituted into equation 2:

At No. 20 mine, $$E_m = \frac{1.0 \times 5.0 \times 0.9}{920} = 4.89 \text{ mm/m}$$

At No. 2 mine, $$E_m = \frac{1.0 \times 7.0 \times 0.9}{1380} = 4.56 \text{ mm/m}$$

hence, the cumulative strain at seabed is 9.45 mm/m.

In the NCB SEH (9) it states that maximum subsidence is often reduced because of the presence of centre gate packs which result in the formation of a hump in the profile centre. Figure 2 shows the schematic diagram of a subsidence profile resulting from the presence of a centre gate, along with the normal profile (no centre gate). The analysis of field data (9) has shown a relationship between the subsidence at the top of the hump and the maximum subsidence expected over a normal panel, Figure 3.

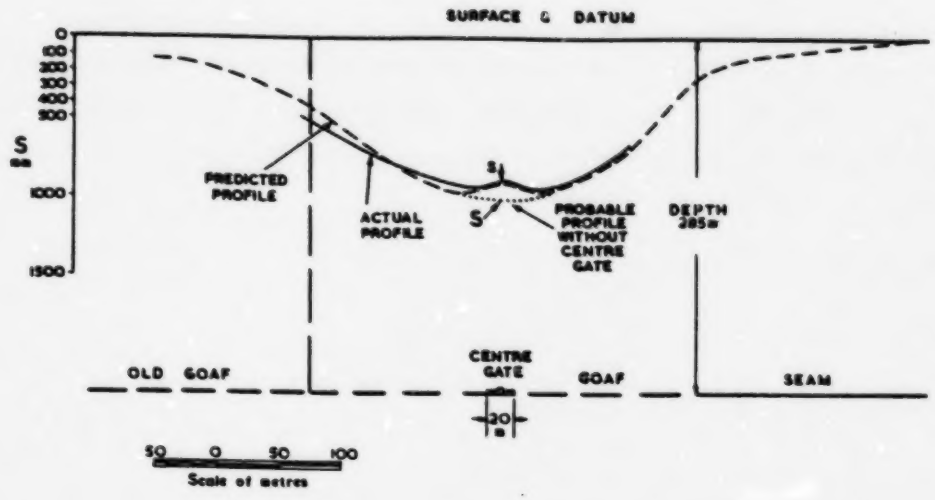

Figure 2 - Schematic diagram showing normal subsidence profile and the effects of a centre gate (9)

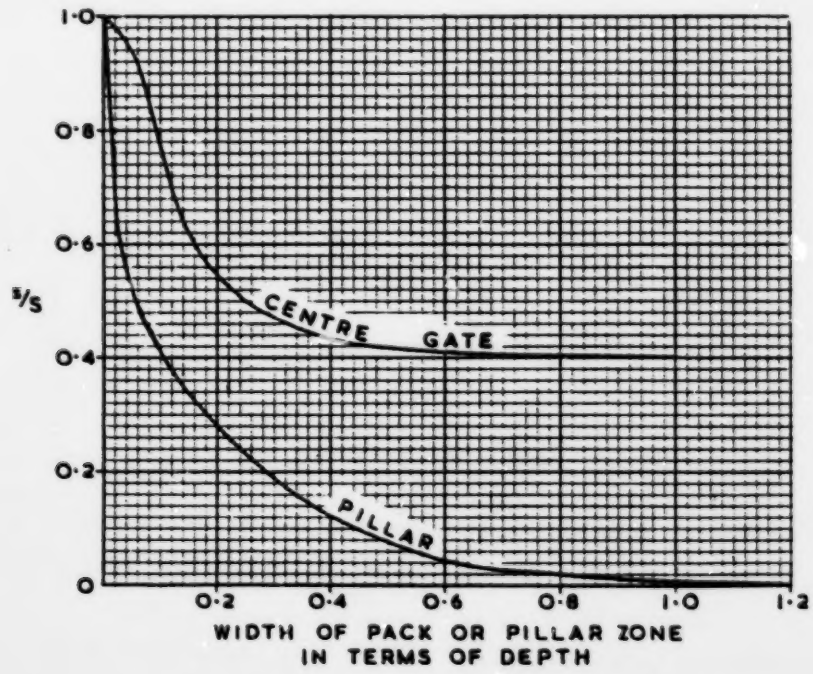

Figure 3 - Relationship between maximum subsidence and the subsidence experienced over a centre gate (9)

Using centre pack widths of 20 and 40 ft respectively (where 40 ft is the total pack width across the centre roadway), based on values obtained for those used in the No. 20 mine workings, the subsidence and tensile strain expected over the No. 20 mine, Harbour Seam area would be:

For a 20 ft pack, $\frac{w}{d} = \frac{20}{920} = 0.02$ and from Figure 2 $\frac{S}{S_{max}} = 0.98$

For a 40 ft pack, $\frac{w}{d} = \frac{40}{920} = 0.04$ and from Figure 2 $\frac{S}{S_{max}} = 0.96$

Using equation 2 with w/d values of 0.02 and 0.04 with a = 0.9 and 0.8,

	w/d	
a	0.02	0.04
0.9	4.41 mm/m	4.32 mm/m
0.8	3.92 mm/m	3.84 mm/m

Therefore, using the maximum tensile strains calculated for the No. 2 mine, Phalen workings (a = 0.9 and 0.8), the resultant cumulative seabed strains are:

a	No. 20 mine	No. 2 mine	Cumulative Strain (mm/m)
0.9	4.41	4.56	8.97
0.9	4.32	4.56	8.88
0.8	3.92	4.05	7.97
0.8	3.84	4.05	7.89

The predicted cumulative tensile strains at seabed over the identified area of the No. 2 and No. 20 mine workings therefore varies between 7.9 and 9.0 mm/m.

In Wardell's 1976 report (6) to the U.S. Bureau of Mines, the value of k (the mining/geological conditions coefficient and assumed in the 1974

report to be k = 1.0) is reduced to k = 0.75 with no explanation for this decrease except for the comment that 'the average value for k in the U.K is 0.75'. In addition, it states that an examination of the literature, at this time, (1976-76), reveals that in Australia and the U.S.A., the values of 'a' have been found to lie between 0.6 and 0.7 compared with the values of 0.8 and 0.9 found in Europe.

If the value of k = 0.75 is used in equation 2, for the No. 2 and No. 20 mine workings, where a = 0.9 and 0.7:

At No. 20 mine, E_m = 3.66 mm/m (a = 0.9) and 2.85 mm/m (a = 0.7)

At No. 2 mine, E_m = 3.42 mm/m (a = 0.9) and 2.66 mm/m (a = 0.7)

The cumulative tensile strains at seabed are therefore 7.08 mm/m (a = 0.9) and 5.51 mm/m (a = 0.7).

If the NCB value of k = 0.66 is used in equation 2 for the No. 2 and No. 20 mine workings, where a = 0.9 and 0.7:

At No. 20 mine, E_m = 3.23 mm/m (a = 0.9) and 2.51 mm/m (a = 0.7)

At No. 2 mine, E_m = 3.01 mm/m (a = 0.9) and 2.34 mm/m (a = 0.7)

The cumulative tensile strains at seabed are therefore 6.24 mm/m (a = 0.9) and 4.85 mm/m (a = 0.7).

In Wardell's 1974 report (4), the maximum tensile strain value for the Lingan mine 1E panel was calculated as 6.75 mm/m, using k = 1.0 and a = 0.9. If the NCB SEH (9) is used, assuming a correction for the panel gradient (1 in 5.5), the seabed tensile strain becomes 4.8 mm/m using k = 0.7 and a = 0.7.

The question regarding the application of existing subsidence guidelines to the Sydney Coalfield therefore hinges around whether the values in equation 2 should be k = 1.0, 0.75 or 0.66 and a = 0.9, 0.8 or 0.7. In the U.K., the analysis of an extensive field data base revealed that maximum subsidence and hence the value of 'a' for any given profile is proportional

to the width and depth of the mining panel. Similar data bases are currently being established in the U.S.A. and other parts of the world for the determination of 'a' values.

With respect to the derivation of the 'k' value, there appears to be absolutely no evidence in either the N. American or European literature for the use in Wardell's 1974 report (4) of the value k = 1.0. The NCB SEH (9) mentions that since 1957 (22) in the U.K., maximum tensile strain was determined using equation 1 where E_m = 0.75 S/h, for panel widths up to 0.7 h. The value of k = 0.75 was determined from the analysis of an extensive field data base, but subsequent work (9) has found it to be only an average value. It is interesting to note that the value of k = 0.75 used by Wardell in the 1976 report (6) to the U.S. Bureau of Mines is in fact the same value used by the NCB in the U.K. between 1957 and 1975. The question must therefore be asked, why in the 1974 Commission of Inquiry report (4) was k taken as 1.0 rather than 0.75.

It is universally recognised that the NCB SEH (9) cannot be used to accurately predict subsidence profiles in the U.S. Appalachian and mid-West Coalfields. However, it should be noted that although the Sydney Coalfield appears to be a northern extension of the Appalachian Coalfield, it also bears marked geological/structural similarities to the U.K. coalfields. It is therefore concluded, that given the wide range of conditions under which the NCB SEH data was collected, the SEH can be applied to the Sydney Coalfield providing it is realised that the error may be greater than the ±10% normally quoted.

Based on the information presented in this report, it is not proposed to suggest 'k and a' values for determining subsidence profiles in the Sydney Coalfield. However, it is strongly recommended that a detailed field program be undertaken to provide sufficient data for the determination of Sydney Coalfield specific 'k and a' values. The field program should attempt to determine and/or monitor both existing subsidence profiles over the current Lingan, Prince and No. 26 mine workings, as well as the real-time development of new profiles over the Lingan-Phalen, Lingan, Prince and proposed Donkin-Morien mines. Finally, until such time as Sydney Coalfield specific 'k and a' values become available, it is thought that the current guideline of 8.5 mm/m should be adhered to, because to date no inundations have occurred in any of the mine workings designed to this value.

CONCLUSIONS

To date, no subsidence data has been obtained to calculate actual seabed strains over the longwall panels or evaluate the factor of safety contained within the existing subsidence guidelines for the Sydney Coalfield. A review of the available data has revealed that a variety of different 'subsidence coefficients' could be substituted into the equation to determine seabed strains. In fact, by a process of pseudo-scientific justification, 'subsidence coefficients' can be substituted into the equation to give almost any desired value of tensile strain at seabed.

It is therefore recommended that a field programme be undertaken to provide sufficient data for the determination of Sydney Coalfield specific 'subsidence coefficients'. This should be implemented as soon as possible in view of the proposed multi-seam mining conditions to be encountered at the Phalen and Donkin-Morien mines. However, until such time as site specific coefficients become available, the current guideline of 8.5 mm/m tensile strain at seabed should be adhered to, because to date no inundations have occurred in any of the mine workings designed to this value.

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